09/564,869

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B32B | A2

(11) International Publication Number: WO 97/27045

(43) International Publication Date: 31 July 1997 (31.07.97)

(21) International Application Number: PCT/US96/20115

(22) International Filing Date: 20 December 1996 (20.12.96)

(30) Priority Data:
60/010,033 12 January 1996 (12.01.96) US

(71) Applicant (*for all designated States except US*): THE BOEING COMPANY [US/US]; P.O. Box 3707, M.S. 13-08, Seattle, WA 98124-2207 (US).

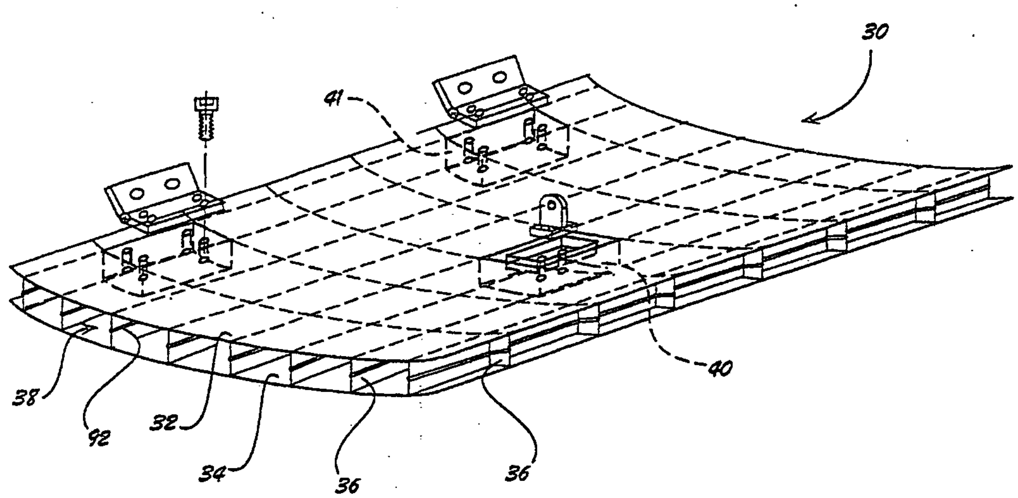
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): BULDHAUPT, Frederick, W. [US/US]; 16206 236th Avenue East, Buckley, WA 98321 (US). FISCHER, John, R. [US/US]; 4417 53rd Avenue S.W., Seattle, WA 98116 (US). KISTNER, Matthew, G. [US/US]; 751 Warner Avenue West, Enumclaw, WA 98022 (US). WILL, Jeffrey, D. [US/US]; 16213 S.E. 178th Place, Renton, WA 98058 (US).

(74) Agent: NEARY, J., Michael; 542 S.W. 298th Street, Federal Way, WA 98023 (US).

(81) Designated States: US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: METAL SANDWICH STRUCTURE WITH INTEGRAL HARDPOINT



(57) Abstract

A superplastically formed, diffusion bonded sandwich structure having integral metal hardpoints, made by joining two superplastic metal core sheets together into a core pack by welding or diffusion bonding along a pattern of lines which form junction lines between the core sheets when the pack is inflated by gas pressure at superplastic temperatures. Face sheets are laid under and over the core pack and metal inserts are interposed between the face sheets and the core. All of the sheets in the pack are sealed together around an outside peripheral edge to create a gas tight envelope. The pack is heated to superplastic temperatures in a cavity in a die, and the top and bottom face sheets are diffusion bonded to top and bottom surfaces of the metal insert by application of heat and pressure from top and bottom inner surfaces of the die cavity. While at superplastic temperatures, the pack is inflated by gas pressure against inside surfaces of a die to form an expanded metal sandwich structure having integral webs and integral hardpoints formed by the metal insert. After forming, the gas pressure is reduced to near atmospheric, the die is opened and the part is removed from the die.

Metal Sandwich Structure with Integral Hardpoint

This invention was disclosed in part in Provisional Patent Application No. 60/010,033 entitled "Multisheet Sandwich Structures", filed on January 12, 1996 by Fred Buldhaupt, Dave Gane, Matt Kistner and Jeff Will.

This invention relates to hardpoints in superplastically formed multisheet sandwich structures, and more particularly to integral hardpoints joined to and joining the top and bottom face sheets of a superplastically formed, diffusion bonded metal sandwich structure by which the sandwich structure can be attached to adjacent structures, pivots, actuators and the like.

BACKGROUND OF THE INVENTION

Multisheet expanded metal sandwich structures made by superplastic forming (SPF) and diffusion bonding have been in use for many years, particularly in the aerospace industry, because of their low cost, good strength and stiffness per unit weight, and high temperature resistance. Various processes for fabricating these structures have been developed in the past, with various degrees of success, and recently these processes have been improved to enable fabrication of these metal sandwich structures with exceptional quality, reliability and efficiency. The new processes are described in Provisional Patent Application No. 60/010,033 entitled "Multisheet Sandwich Structures", filed on January 12, 1996 by Fred Buldhaupt, Dave Gane, Matt Kistner and Jeff Will.

One persistent problem that has been encountered with the use of these metal sandwich structures is connecting them with adequate load transfer capacity to adjacent structure in the assembly of which they are a part. The top and bottom face sheets of the sandwich structure are typically thin titanium sheets which cannot bear the

distributes the connection forces evenly to the metal sandwich structure without damage, and providing the possibility of sinking the fastener heads flush with the outside surface of the part.

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a method of attaching a superplastically formed, diffusion bonded sandwich structure to adjacent structure. Another object of this invention is to provide a method of making a metal sandwich structure having an integral hardpoint at any desired locations in the structure, by which the sandwich structure can be connected to adjacent structures in the assembly in a manner that evenly distributes forces exerted by the adjacent structure on the sandwich structure. A further object of this invention is to provide a sandwich structure having an integral hardpoint by which the sandwich structure can be connected to adjacent structure in the assembly providing high load transfer capability and fatigue tolerance.

These and other objects of the invention are attained in a superplastically formed, diffusion bonded sandwich structure having an integral metal hardpoint, made by joining at least two superplastic metal sheets together into a pack of three or more sheets by welding or diffusion bonding the two sheets along a pattern of lines which form junction lines between the sheets when the pack is inflated by gas pressure at superplastic temperatures. At least one metal insert is interposed between at least two of the sheets and all of the sheets in the pack are sealed together around an outside peripheral edge to create a gas tight envelop. The pack is heated to superplastic temperatures and the top and bottom face sheets are diffusion bonded to top and bottom surfaces of the metal insert by application of heat and pressure from top and bottom inner surfaces of

Fig. 10 is a sectional elevation of an edge portion of a pack that is superplastically formed and diffusion bonded to make the part shown in Fig. 1;

Figs. 11A-11E are schematic elevations of the pack used to make the part shown in Fig. 1, showing several stages in the forming process;

Figs. 12A-12C are sectional elevations of the core pack shown in Fig. 4 in the region of one of the laser welds, showing several stages in the formation of the webs;

Figs. 13 and 14 are sectional elevations of webs formed around resistance and laser welds, respectively, on a core pack;

Fig. 15 is a perspective view of a peripheral frame version of a metal sandwich part, partially broken away to show the interior space inside the panel showing the webs;

Fig. 16 is a perspective view of a stepped block version of a metal sandwich structure in accordance with this invention;

Figs. 11-19 are sectional elevations showing three stages of a prethinning process used to form the core without excessive thinning at the corners of the webs;

Figs. 20 and 21 are sectional elevations showing two stages of forming a truss core metal sandwich structure with a hardpoint in accordance with this invention; and

Figs. 22 and 23 are sectional elevations showing two stages of variant of the truss core forming process shown in Figs. 20 and 21.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning now to the drawings, wherein like reference numerals designate identical or corresponding parts, and more particularly to Fig. 1 thereof, a multisheet superplastically formed, diffusion bonded metal sandwich part 30 such as an access port cover or door made in accordance with this invention is shown having a top face sheet or skin 32, a bottom face sheet or skin 34 spaced apart from the top face

forms a closeout of the edge of the metal sandwich part 30, described in more detail below in conjunction with Fig. 15.

The sandwich structure shown in Fig. 1 is made from four sheets of a metal, such as titanium 6-4 alloy, which has super-plastic and diffusion bonding characteristics. Superplastic characteristics include the capability of the metal to develop unusually high tensile elongations and plastic deformation at elevated temperatures, with a reduced tendency toward necking or thinning. Diffusion bonding refers to metallurgical joining of two pieces of metal by atomic co-mingling at the faying surface of the two pieces when they are heated and pressed into intimate contact for a sufficient time. It is a solid state process resulting in the formation of a single piece of metal from two or more separate pieces without a discernable junction line between them, and is characterized by the absence of any significant change of metallurgical properties of the metal, such as occurs with other types of joining such as brazing or welding. The characteristics of superplastic forming and diffusion bonding are now reasonably well understood, and are discussed in detail in Patent Nos. 3,927,817 to Hamilton and 4,361,262 to Israeli.

Turning now to Fig. 2, a stack 42 of four sheets that make up the sandwich structure shown in Fig. 1 is shown in exploded form to shown the relative positions of the sheets and the relative positions of the features on and between the sheets. The stack 42 of sheets and hardpoint components of Fig. 2 is shown in Fig. 3 in their configuration following superplastic forming and diffusion bonding. The stack 42 includes two core sheets 44 and 46 and top and bottom face sheets 48 and 50. A core gas fitting 52 is inserted between the two core sheets 44 and 46 that are later welded together to make up a core pack 45. The core gas fitting provides a connection to a forming gas supply system for inflation of the core pack 45 during superplastic forming, wherein the core pack 45 is superplastically inflated as illustrated in Fig. 5

off compound such as boron nitride to prevent unintended diffusion bonding. For large area surfaces, the boron nitride may be dissolved in a solvent such as a mixture of water and alcohol and sprayed with an electrostatic sprayer onto the entire surface area of the one side of the one sheet. The water and alcohol evaporate, leaving a thin even coating of boron nitride on the surface of the titanium sheet. For smaller surfaces, the stop-of may be sprayed from an aerosol can of a solution of boron nitride in an alcohol solution that is commercially available from the Cerac Company in Milwaukee, Wisconsin. The stop-off, if used, is carefully excluded from the region between the sheets 44 and 46 where the hardpoint 40 is to be, since diffusion bonding in that area is desired.

The coated sheet is aligned with and abutted against the other sheet, with the boron nitride coated face facing the other sheet. The two core sheets 44 and 46 are laser welded in the pattern shown in Figs. 2 and 4 on a laser welding apparatus shown in Figs.6A and 6B, purchased from Convergent Energy Corp. in Sturbridge, Massachusetts. The apparatus 59 includes a CNC motion control table 60 on which the sheets 44 and 46 are placed and secured in an aligned stack. A vertically extendable clamping actuator such as a powered plunger is mounted over the table 60. The plunger has a fitting on which a pressure trolley 62, shown in more detail in Figs. 7 and 8, is mounted for exerting a vertical force on the sheets to press them into intimate contact during laser welding by a laser beam aimed vertically downward through the center of the trolley 62 at the table.

The motion control table 60 has a series of parallel grooves 64 opening upwardly in its upper surface, and a perforated tube 66 in each groove. The tubes 66 are connected to a manifold that is connected through a pressure control regulator (not shown) to a supply of argon gas. Argon is admitted through the tubes to flood the area between the table 60 and the bottom core sheet 46 and displace oxygen and nitrogen from the area. As shown in Fig. 6B, the area of the

In use, a pair of core sheets 44 and 46 are laid on the table 60 and secured thereon by clamps 88. The argon gas is turned on to flood the underside of the bottom core sheet 46 through the tubes 66 with inert gas and displace the oxygen and nitrogen from the region between the table 60 and the underside of the sheet 46. The flow rate will depend on the table size and number of grooves, but for a table 36" square, a flow rate of about 20 cubic feet per hour is sufficient. The controller for the table actuators is programmed with the speed and dwell of the table movement and the spacing between adjacent welds. The trolley 60 is aligned with the plane of its wheels 86 parallel with the grooves 64 in the table 60, and the vertical motion mechanism on which the trolley 62 is mounted is lowered to engage the wheels 86 with the top surface of the top sheet 44. The vertical extension of the vertical motion mechanism is selected to deflect the spring loops 78 to the extent necessary to produce the desired compressive force exerted by the wheels 86 on the top sheet 44. For example, a 38 pound force can be exerted by two titanium spring loops 1/2" wide and 3 1/2" long when deflected about 3/4". This would be sufficient force to press two titanium alloy sheets 0.025" thick into such intimate contact that an excellent laser weld, with minimal or no porosity, is obtained.

Instead of the spring mounted wheels 86, the trolley 62 may be provided with multiple ball rollers, six rollers for example, each roller mounted on the end of a piston that is spring or gas pressure biased in a cylinder attached to the trolley for use in circumstances where curved weld lines are desired, especially small radius curves that the wheels 86 would have trouble following.

The helium gas is turned on at a flow rate of about 40 cubic feet per hour and after purging the air from the sheet metal enclosure 76, the laser is turned on with a power of about 650 watts, continuous wave. At the start of the weld, the laser is allowed to dwell for about 0.25 seconds at the

in a laser weld which otherwise occurs when the laser power is terminated abruptly.

The weld pattern, shown schematically in Figs. 2 and 4, is in the form of a series of orthogonally aligned crosses 94, or considered differently, is a grid pattern with interuptions or gaps 96 in the weld lines midway between each intersection 98 in the weld lines. The gaps 96 in the weld lines 92 provide a passage through which forming gas can flow when the core pack 45 is superplastically formed by heating to about 1650°F in a die and injecting forming gas through the core gas fitting 52, as illustrated schematically in Fig. 5. When the core pack 45 is inflated, the gaps 96 open to provide near circular openings 100 in webs 36 formed by the material of the top and bottom core sheets 44 and 46 as the material stretches superplastically away from the laser welds 92.

After the grid pattern is laser welded into the sheets 44 and 46, the sheets 44 and 46 are seal welded completely around their periphery and around the core gas fitting 52 to fully seal the periphery of the core pack 45. A convenient type of welding for this purpose is gas tungsten arc welding wherein the welding arc can be directed into the edge face of the sheets 44 and 46. A conventional stainless steel compression coupling such as a Swagelock coupling (not shown) is attached to the gas fitting 52, and one end of a short length of stainless steel gas tubing is attached to the compression coupling. The other end of the tube is pinched shut and welded closed to seal off the interior of the core pack 45 against intrusion of cleaning solution for the following cleaning operation.

The sealed core pack 45 is cleaned by immersion in the alkaline bath and the pickling bath as describe above and surfaces which are to be diffusion bonded are wiped with a fabric wad wetted with punctilious alcohol, as also described above. The cleaned core pack 45 is assembled between the cleaned face sheets 48 and 50, with the envelop gas fitting 54 positioned in the notch 56. The hardpoints 40 and 41 are

The external surfaces of the pack 110 are coated with a parting agent, such as the boron nitride stop-off described above. Compression fittings are attached to the gas fittings 52 and 54 and gas lines from a forming gas control system, such as that described in U.S. Patent No. 5,419,170 to Sanders et al. are connected to the compression couplings. The full pack is purged with dry inert gas, such as argon, to remove air and moisture from inside the envelop pack 49 and the core pack 45. This may be accomplished with several cycles of alternate vacuum suction and backfilling with argon under a pressure of about 0.5 PSI in the envelop pack 49 and about 10 PSI in the core pack 45, until the interior of the packs 45 and 49 are purged clean of air and moisture. Alternatively, the two nested envelopes may each be provided with two gas fittings and dry inert gas such as argon may be pumped in one fitting in each envelope and exhausted out the other fitting. The packs 45 and 49 are now pressurized with argon to separate the surfaces from each other. The pressure inside the core pack 45 is preferably higher than the pressure in the envelop pack 49 because the grid welds 92 tend to hold the core sheets 44 and 46 together more tightly than the peripheral weld holds the face sheets 48 and 50 together, due to the smaller radius on the core pack 45. The initial pressure is about 0.1 PSI in the skin zone within the envelop pack 49 and about 10 PSI in the core pack 45. This provides sufficient pressure to prevent contact and premature diffusion bonding between the facing surfaces of the sheets, but not so high as to cause premature pillowing of the core envelop or tearing of the sheets at the laser welds or the peripheral welds. The pressurized pack 110 is placed in a die 112 that is preheated to about 1600°F, and the die is closed and held closed with a superplastic forming press (not shown) against pressure of forming gas that will be used to superplastically deform the elements of the core pack and envelope pack. The die may be provided with grooves extending from an internal cavity to the exterior in which the gas fittings 52 and 54 lie to avoid

If it is desired to have sealed through openings in the part, the full pack 110 may be laser welded in a circle around the region where the opening is to be located. The interior of that region may be cut out with a laser cutter, which uses the same laser and table 60, but uses a high pressure gas nozzel instead of the gas flood nozzle shown in Fig. 7. The full pack is placed on a protective mat to prevent cutting or splattering of the surface of the table 60 when the laser cuts through the pack when cutting out the hole in the center of the seal weld region. A sleeve having the same height as the sandwich structure part is inserted in the opening cut out by the laser, and the full pack 110 with the sleeves installed in the openings is placed in the die cavity 114 and is superplastically formed around the sleeves. If the sleeve is a non-superplastic material such as stainless steel, it may be removed or retained, whichever is desired for the application. If a superplastic material such as titanium is used, it will diffusion bond in place in the opening and form the interior of the opening. The sleeve may be provided with a threaded insert for threaded connection to the part later, or the "sleeve" may be a solid titanium slug that can be drilled and tapped after the part has been formed for a connection hardpoint to the sandwich structure.

Turning now to Fig. 16, another embodiment of the four sheet expanded metal sandwich structure is shown having a stepped block 120 having an upper portion 122 and a longer, wider lower portion 124, meeting at an intermediate ledge or shoulder 126 providing an upwardly facing surface to which a core pack 145 is laser welded along a continuous peripheral weld line 146 that completely encircles an opening 148 cut in the core pack to receive the upper portion 122 of the stepped block 120. The core pack 145 is otherwise identical to the core pack 45 in the embodiment of Figs. 2 and 4 and the core pack fabrication procedures are the same. The opening 148 in the core pack 145 can be cut after the core pack is cleaned, or it can be laser cut and sealed prior to cleaning. The webs

The separation of the top and bottom face sheets 32 and 34 from the core pack 45 provided by the peripheral frame 160 makes possible an improvement in the core forming process which solves a corner thinout problem that has plagued manufacturers of the four sheet metal sandwich structures for years. The thinout problem is an excessive thinning of the web 36 where it joins the top and bottom sheets 32 and 34 at the corners 180 of the cells 38. The thinout is a consequence of the core sheets 44 and 46 sticking to the face sheets 32 and 34 when the core 45 is inflated at superplastic temperatures. The portions of the core sheets 44 and 46 that are stuck to the face sheets 32 and 34 can no longer elongate superplastically so all additional elongation thereafter is done in the portions of the core sheets 44 and 46 that are not yet in contact with the face sheets 32 and 34. The consequence is increasing thinout of the core sheets 44 and 46 as they are formed toward the corners 180. The conventional solution to the problem is to use core sheets that are thick enough to produce adequate corner thickness even after such thinout. However, this technique results in thicker webs 36 and top and bottom sheets than is otherwise necessary, and more weight than desired.

The corner thinout problem is solved by prethinning the core sheets 44 and 46 in the central areas of the cells 38 within the weld lines 92, as shown in Figs. 17-19. The core pack 45 is made normally as shown in Fig. 2, but without the hardpoint blocks 106 and 108. The core pack 45 is placed in a die 190 having pockets 192 located centrally above and below the cells 38 between the weld lines 92. The die 190 has no pocket in central areas where a central hardpoint is to be located. The core pack 45 is heated to superplastic temperatures and is expanded by gas pressure through the gas fitting 52 to form the core sheets 44 and 46 into the pockets 192 in the top and bottom halves of the die 190, forming bulges 194 and 196 in the core sheets 44 and 46, shown partially formed in Fig. 18 and fully formed and assembled in

sheets 202 and 204 and to the truss webs 206 to avoid high stress concentrations on the thin sheets in the structure 200.

As shown in Fig. 21, the structure 200 is made from a three sheet core pack 214, top and bottom face sheets 202 and 204, and top and bottom half blocks 216 and 218. The core pack 214 is made up of three sheets of metal having superplastic and diffusion bonding capabilities, such as titanium alloy described above, which is cleaned and welded with partial penetration laser welds in a pattern shown in Fig. 21. A full penetration laser weld 220 is made around the area covered by the half blocks 216 and 218 to isolate the interior of the core pack 214 in that area from forming gas pressure to prevent undesired gas flow through holes by which the half blocks are pinned to the core pack 214. A gas fitting is welded into the pack 214 for connection through a gas pressure control system, described above, to a source of forming gas such as Argon under pressure. The pack 214 is seal welded around its entire periphery and is cleaned as described above.

An envelope pack 222 is assemble as shown in Fig. 21 from the core pack 214, the two half blocks 216 and 218, and the face sheets 202 and 204. The half blocks are pinned to the core pack 214 by accurately positioning them at the desired location and drilling a pair of holes 224 through the half blocks and the core pack, and driving a pin through the holes 224 to lock the half blocks in position.

The face sheets 202 and 204 are seal welded around their outside periphery to the outside periphery of the core pack 214. If the half blocks are thin enough, the face sheets 202 and 204 may be flexed inward to the core pack 214 and seal welded thereto around an envelope gas fitting like the gas fitting 54, communicating with the space between the core pack 214 and the face sheets 202 and 204. Alternatively, the face sheets 202 and 204 may be preformed as indicated at the right side of Fig. 21 with a peripheral lip 226 that can be seal welded to the core pack 214 and a wall section 228 by which

pressure to the core pack is increased to exert pressure on the top and bottom core sheets to press them against the face sheets 202 and 204 to facilitate diffusion bonding. The diagonal webs 206 project from the middle of the hardpoint 210 and are diffusion bonded thereto to further spread the load exerted on the hardpoint evenly through the sandwich structure 200. After diffusion bonding is complete, the gas pressure is lowered and the die is opened to remove the part from the die cavity. The part is complete except for edge trimming and machining or drilling attachment surfaces such as holes or the like in the hardpoint 210.

Naturally, as many hardpoints as are needed may be made in the part 200 and a peripheral hardpoint in the form of a peripheral frame 160 may be made in the structure 200 if a solid peripheral closeout or edge attachment structure are desired, independently of the standoff function provided by the peripheral frame. The hardpoints may be machined in any desired way to provide recesses for flush mounting of fasteners or other attachment hardware, such as the shackle shown exploded out of its recess in the hardpoint 40 in Fig. 1. They may also be drilled and tapped for receiving threaded fasteners, or drilled to receive bolts which can be torqued tight to preload the fastener in tension for secure attachment without crush the sandwich structure, since the hardpoint has sufficient compressive strength to react the tensile force exerted by the bolt.

Turning now to Figs 22 and 23, an expanded metal truss core sandwich structure 240 is shown having a top face sheet 242 and a bottom face sheet 244 defining therebetween an open space. A plurality of webs 246 extending diagonally between the face sheets 242 and 244 couples the face sheets and stiffens the structure 240. A hardpoint 250 is interposed between and diffusion bonded to the face sheets 242 and 244, providing an attachment structure by which the sandwich structure 240 may be attached to adjacent parts of a larger assembly, as explained above. The diagonal webs 246 are also

sheets 242 and 244, respectively, and the top face sheet diffusion bonds to the sides of the hardpoint 250 forming an integral structure through which internal stresses in the sandwich structure 240 may flow evenly without stress concentrations at any particular point.

After diffusion bonding is completed, the pressure is reduced to near atmospheric. The gas fittings are not opened to avoid the aspiration of oxygen into the hot core of the part 240 until it is cool. A slight pressure is maintained in the core to prevent the cooling part from pulling a vacuum and buckling under atmospheric pressure. The die is opened and the part is removed from the die while still hot so that another part may be made without wasting heat from the die.

Obviously, numerous modifications and variations of the preferred embodiments described above will occur to those skilled in the art in light of this disclosure. Thus, it is expressly to be understood that these variations and modifications, and the equivalents thereof, are to be considered to be within the spirit and scope of the invention as defined in the following claims, wherein we claim:

4. A method as defined in claim 1, wherein:

said inflating of said pack includes inflating said upper and lower face sheets against said upper and lower inside surfaces of said die cavity, and expanding said core against inside surfaces of said upper and lower face sheets and diffusion bonding said core thereto.

5. A method as defined in claim 4, wherein:

said pack includes an upper face sheet, a lower face sheet, and a core of an upper core sheet and a lower core sheet joined together by welding or diffusion bonding along said pattern of lines that will form said junction lines;

said insert includes an upper lower half block and a lower half block;

said upper half block is interposed between said upper face sheet and said upper core sheet; and

said lower half block is interposed between said lower core sheet and said lower face sheet of said pack.

6. A method as defined in claim 5, wherein:

said expanding of said core includes inflating said core to press said upper core sheet upward into contact with said upper face sheet and with a side surface of said upper half block, and to press said lower core sheet into contact with said lower face sheet and with a side surface of said lower half block.

7. A method as defined in claim 6, wherein:

said side surfaces of said upper half block are flared upward and said side surfaces of said lower half block are flared downwardly to provide a draft angle for smooth transition of forces from said insert to said upper and lower face sheets and said webs formed by siad core sheets.

8. A method as defined in claim 1, further comprising:

sheets are diffusion bonded to said top and bottom core pack sheets.

12. A method as defined in claim 1, wherein:

said sealing of said sheets around said outside periphery is by seal welding.

13. A method as defined in claim 12, wherein:

said metal insert is pinned to said one metal sheet to hold said insert in position while said pack is assembled and seal welded around said outside periphery.

14. An expanded metal sandwich structure having integral internal stiffening webs and at least one integral metal hardpoint, comprising:

a top sheet of superplastic metal, and a bottom sheet of superplastic metal, said top and bottom being spaced apart and defining therebetween an enclosed internal space within said sandwich structure;

a plurality of webs integrally joined with and joining said top and bottom sheets, said webs spanning said enclosed internal space;

at least one metal hardpoint integrally joined with said top sheet and said bottom sheet and spanning said enclosed internal space, said hardpoint forming a load path between said top and bottom sheets for distributing forces exerted on said sandwich structure by attachment hardware by which said sandwich structure is connected to adjacent structure.

15. An expanded metal sandwich structure as defined in claim 14, wherein:

said metal insert is also integrally joined to at least one of said webs and forms a load path between said web and said hardpoint for distributing said forces exerted on said

thereof, joined to and extending between said top and bottom sheets, and integrally joined to said webs.

22. An expanded metal sandwich structure as defined in claim 15, wherein:

said webs are in the form of diagonal truss webs extending at an angle between said top and bottom face sheets and connected to said hardpoint.

23. A structural assembly having an expanded metal sandwich part and an adjacent structure to which said part is attached, said part comprising:

a top sheet, a bottom sheet spaced from said top sheet, integral webs spanning said space between said top and bottom sheets and joined integrally thereto, and an integral metal hardpoint integral with said top and bottom sheets.

24. A structural assembly as defined in claim 23, further comprising:

engagement surfaces in said hardpoint engaged by attachment hardware extending between said adjacent structure and said metal sandwich part, said attachment hardware existing in a state of tension to securely fasten said adjacent structure and said part together.

25. A structural assembly as defined in claim 24, wherein:

said hardpoint is in the form of a peripheral frame encircling said part as a peripheral structure thereof.

26. A structural assembly as defined in claim 25, wherein:

said peripheral frame has a continuous peripheral edge surface extending around said part and directly connecting and integrally joined to outer peripheral edges of said top and bottom sheets, said peripheral edge of said frame constituting a closeout of said part flush with said to outer peripheral edges of said top and bottom sheets.

sandwich structure and said adjacent structure that distributes loads therebetween evenly in said sandwich structure.

31. A method as defined in claim 30, wherein:

said opening is a hole drilled through said hardpoint;

said attachment hardware is a bolt extending through said hole and through another hole in said adjacent structure and fastened with a nut tightened to exert a tensile force holding said adjacent structure to said sandwich structure, said hardpoint having sufficient compressive strength to react said tensile force exerted by said nut and bolt.

32. A method as defined in claim 30, wherein:

said opening is a hole drilled into said hardpoint and tapped with helical threads;

said attachment hardware is a machine screw extending into said hole and through another hole in said adjacent structure, said machine screw having helical threads engaged with said hole helical threads and torqued down to exert a tensile force holding said adjacent structure to said sandwich structure, said hardpoint having sufficient strength to react tensile force exerted by said machine screw.

33. A method as defined in claim 30, wherein:

said hardpoint includes a peripheral frame surrounding said sandwich structure and constituting a peripheral edge thereof.

34. A method as defined in claim 33, wherein:

said peripheral frame is a continuous structure and constitutes an upstanding peripheral closeout around said sandwich structure.

preforming two core sheets of a core at selected areas in the central area of cells of said core in a bubble to prethin said core sheets in said selected areas;

assembling said face sheets and said core into a pack with said face sheets encompassing said core;

inserting a first gas fitting communicating from outside said pack to core interior space within said core between said core sheets, and inserting a second gas fitting communicating from outside said pack to pack interior space within said pack between said core and said face sheets;

sealing said face sheets and said core together around an outside peripheral edge of said pack into two nested airtight envelopes including an inner envelope and an outer envelope, said inner envelope comprising said core, and said outer envelope comprising said face sheets;

heating said pack to superplastic temperatures inside a die having a die cavity with interior surfaces shaped like said outer mold line of said metal sandwich structure;

while at superplastic temperatures, inflating said outer envelope against said die cavity interior surfaces by injecting forming gas into said outer envelope through said second gas fitting, and inflating said inner envelope against said outer envelope by injecting forming gas into said inner envelope through said first gas fitting;

diffusion bonding said core sheets around said junction lines to portions of said core sheets on opposite sides of said junction lines, and to said face sheets to produce said webs around said cells;

whereby thinout of said webs at junction regions of said webs and said face sheets is minimized.

41. A method as defined in claim 40, further comprising:

inserting a hardpoint in the form of a peripheral frame between said face sheets and surrounding said core, said peripheral frame constituting a peripheral edge of said sandwich structure;

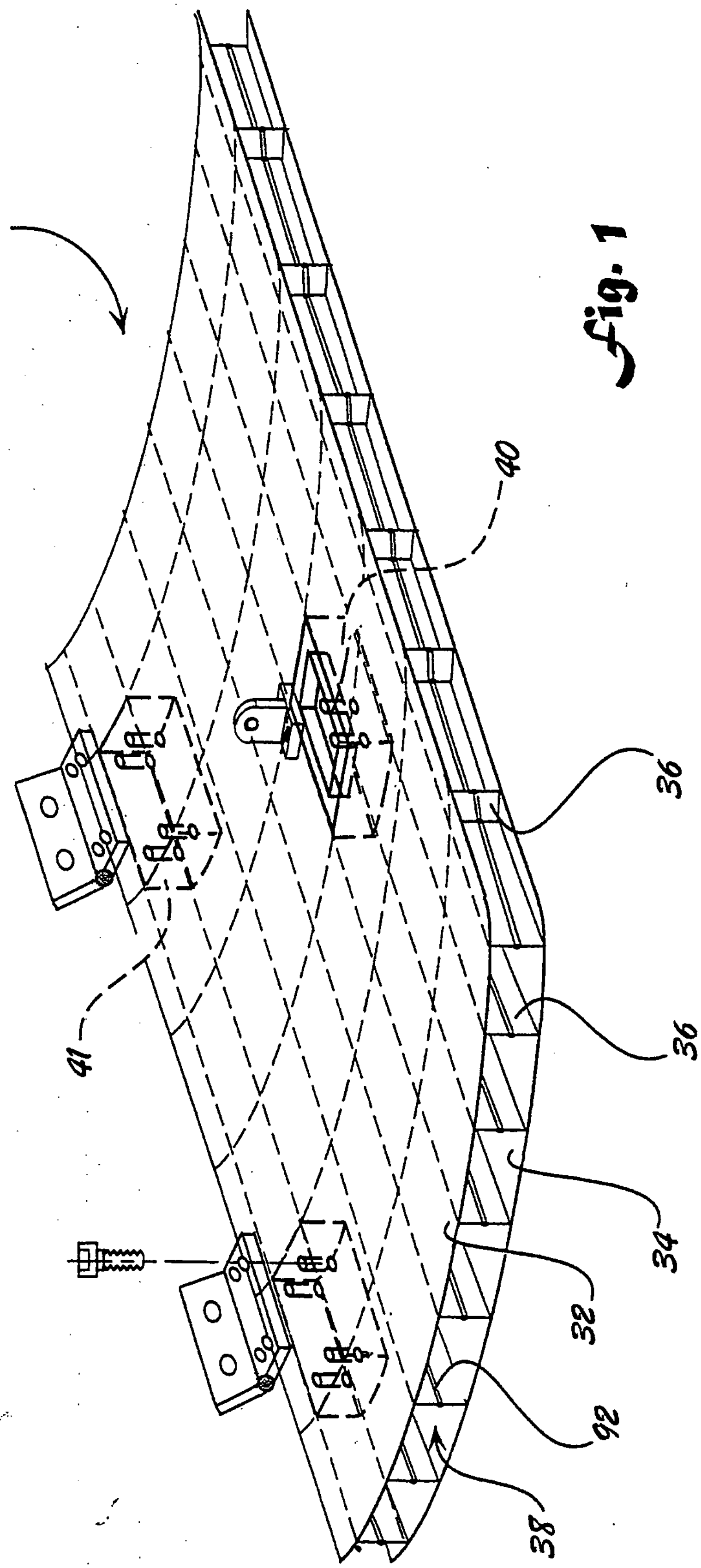


fig. 1

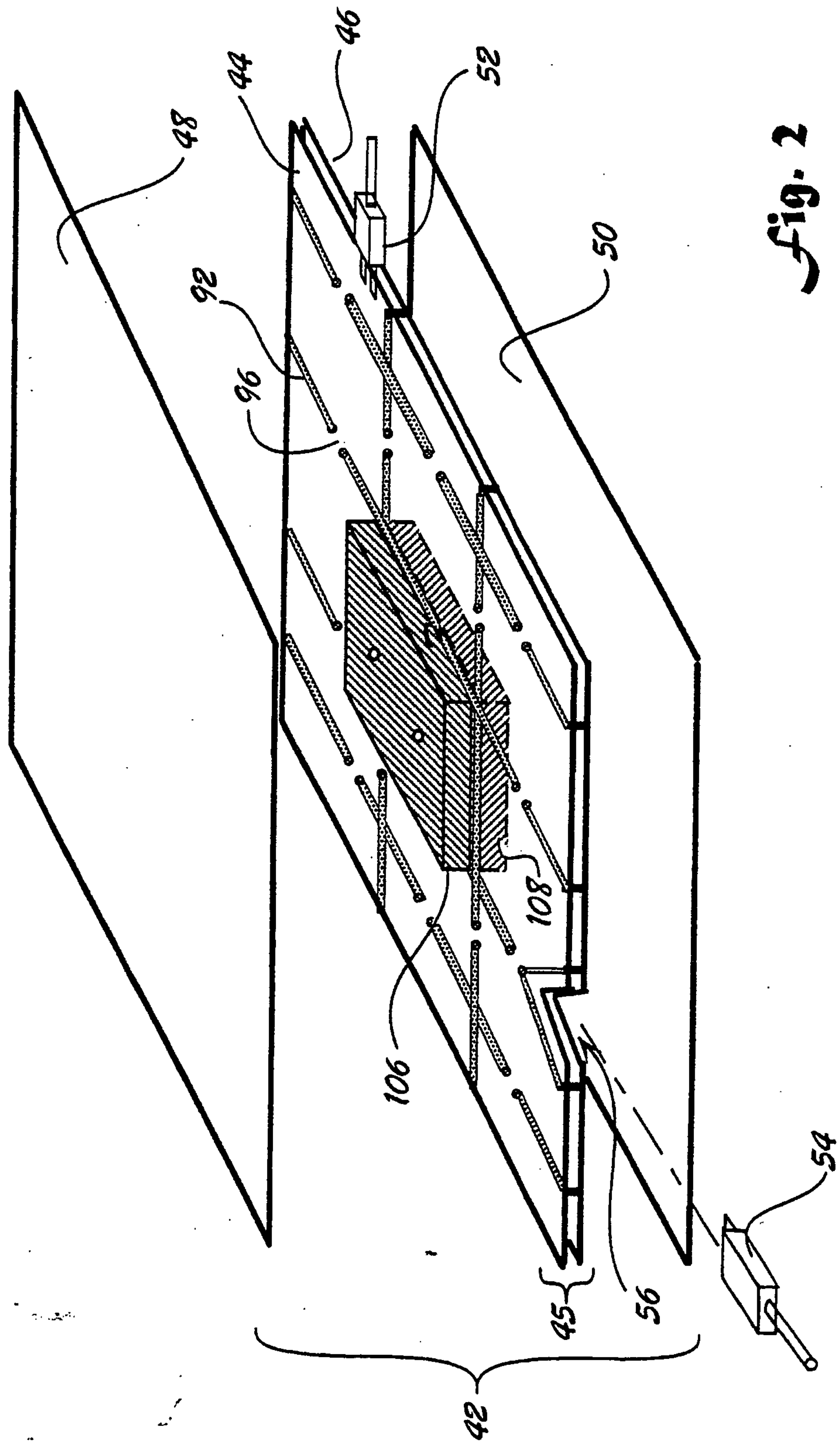


Fig. 2

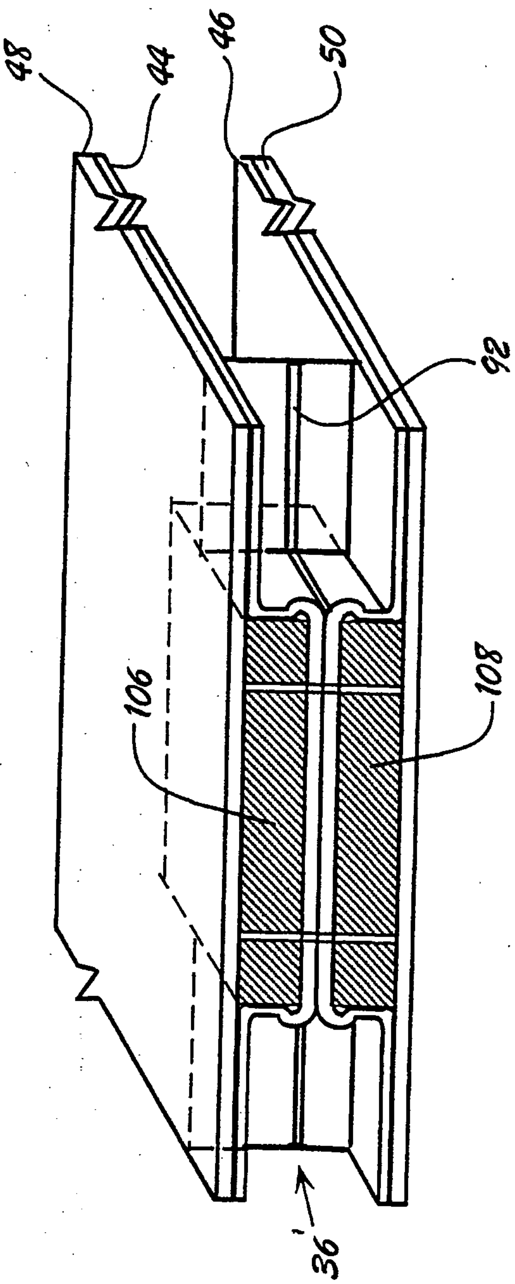


Fig. 3

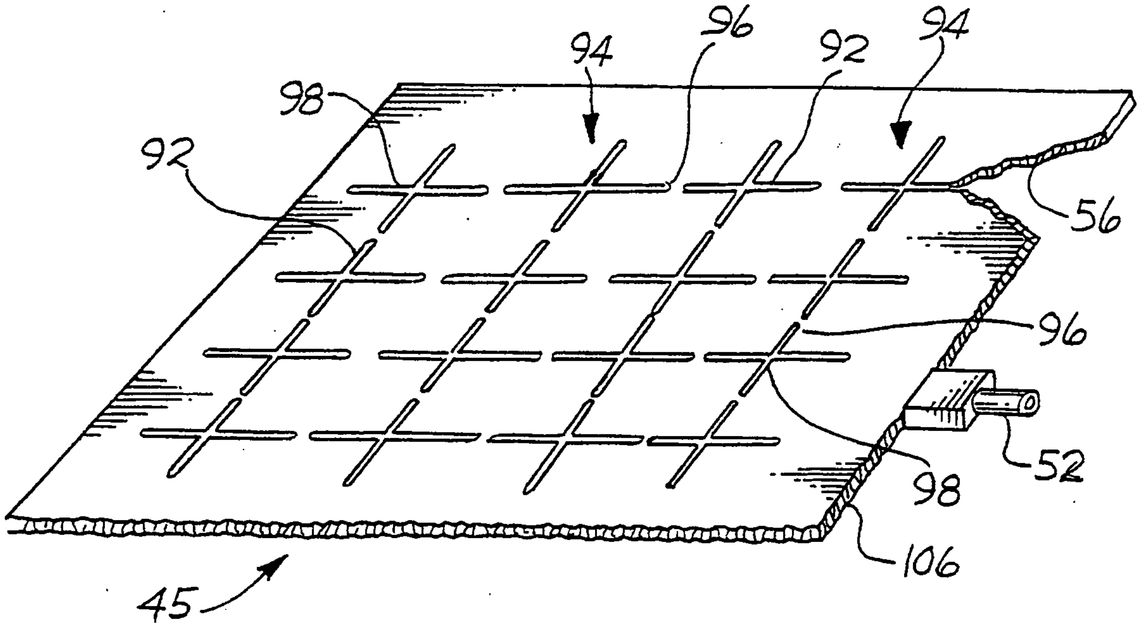


Fig. 4

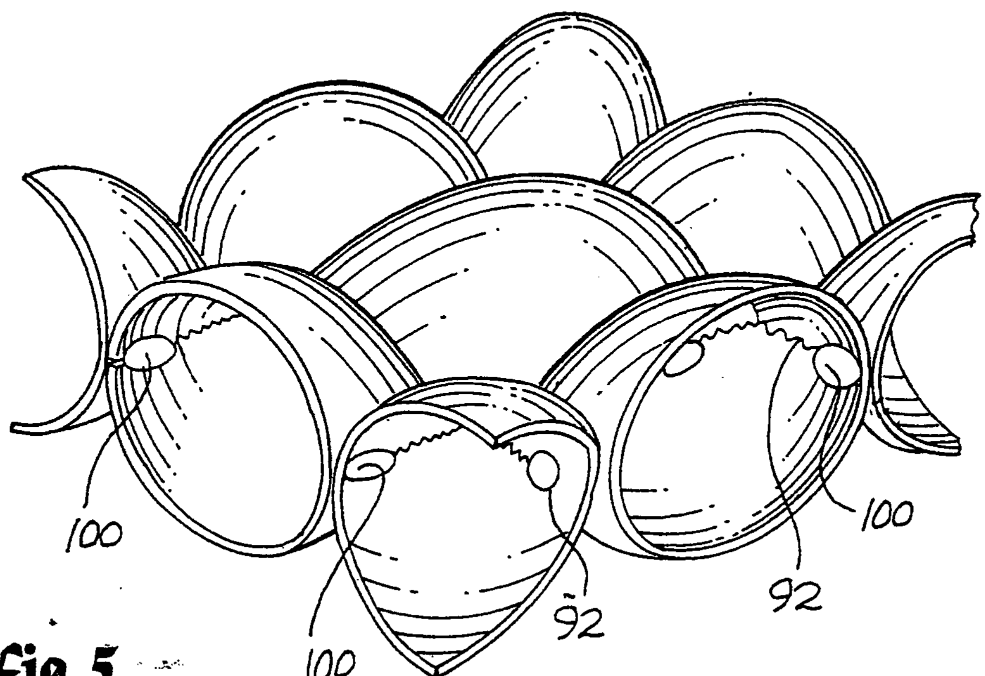


Fig 5

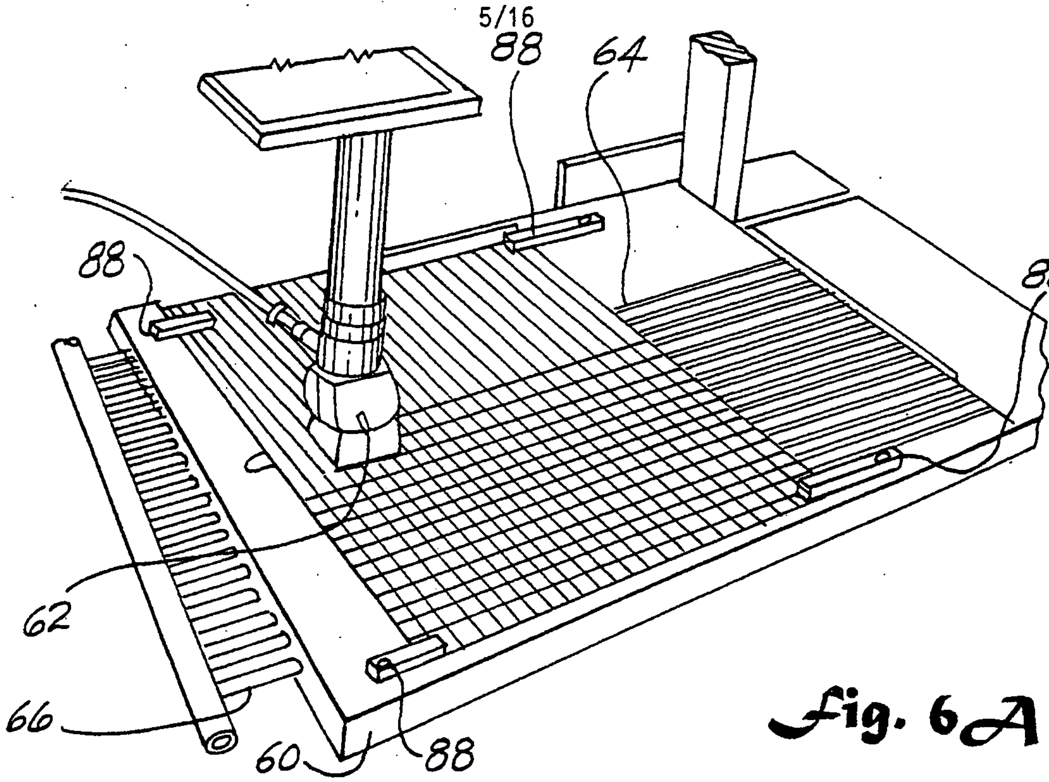
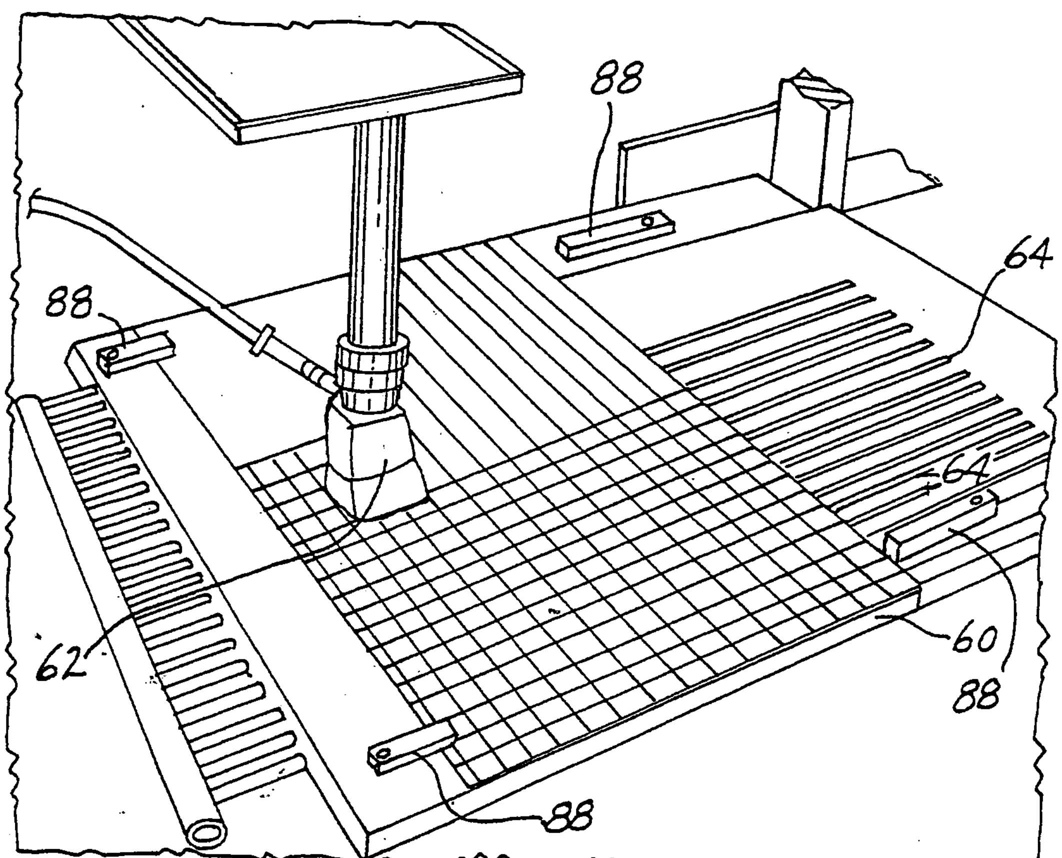


Fig. 6A

Fig. 6B



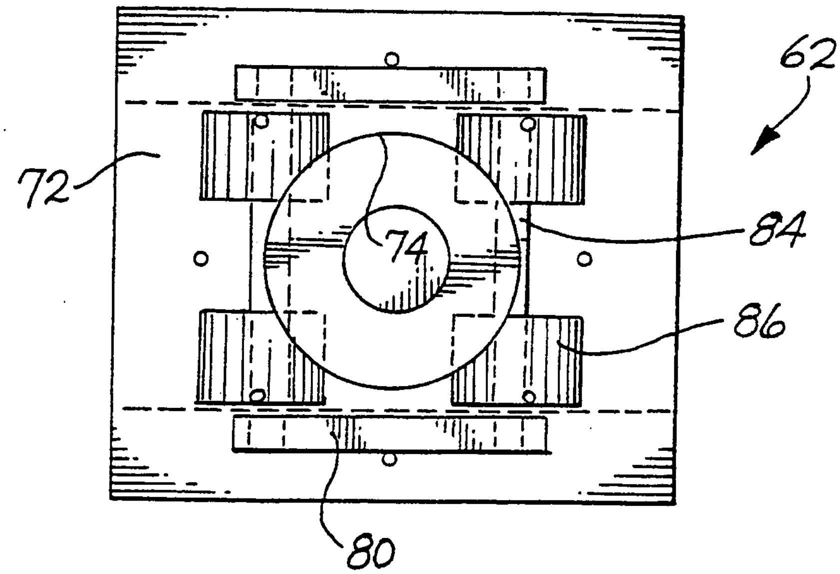


Fig. 8

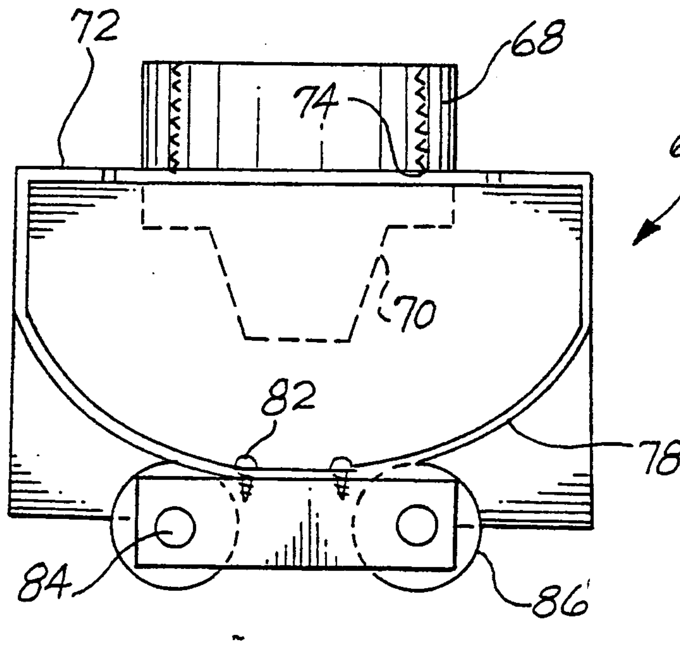


Fig. 7

Fig. 9A

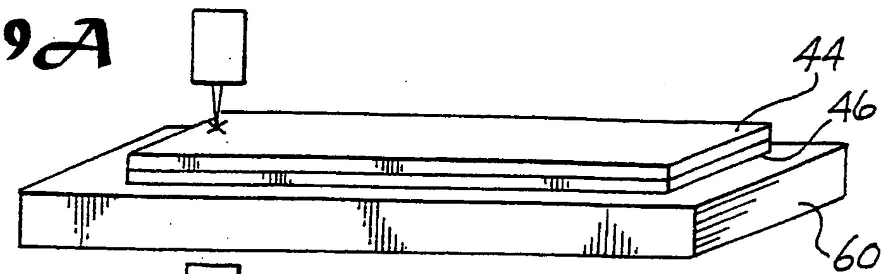


Fig. 9B

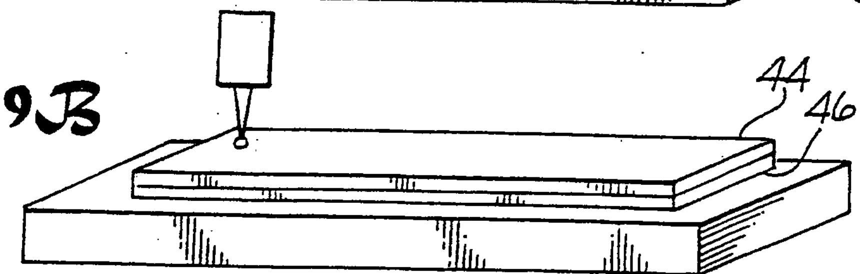


Fig. 9C

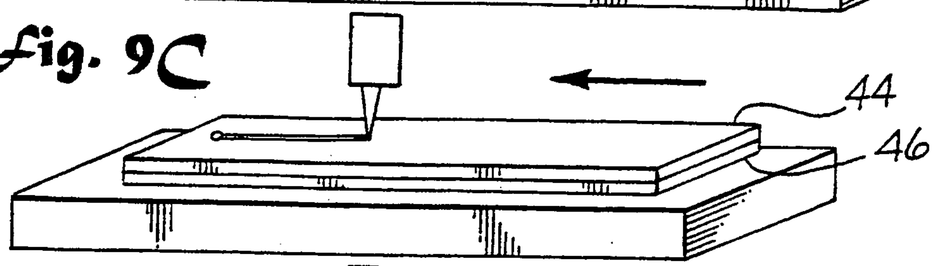


Fig. 9D

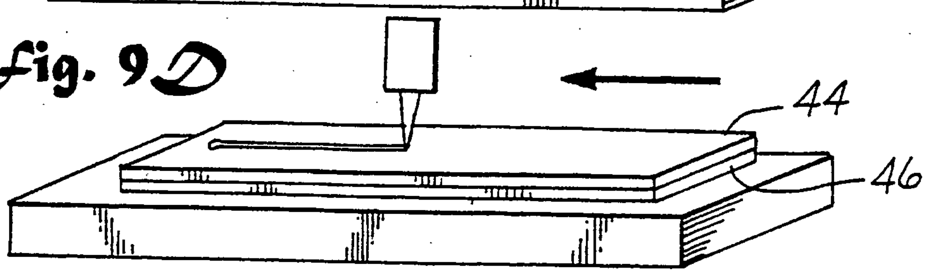


Fig. 9E

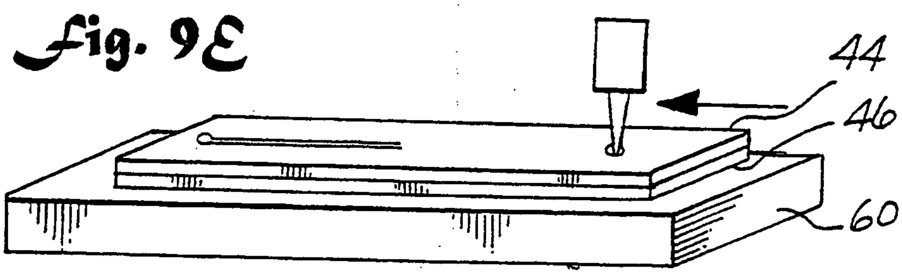


Fig. 9F

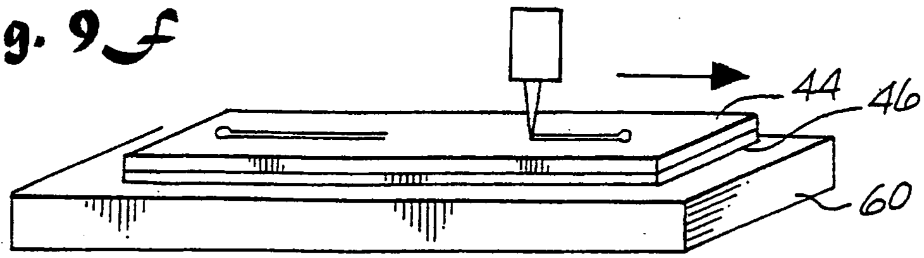


Fig. 9G

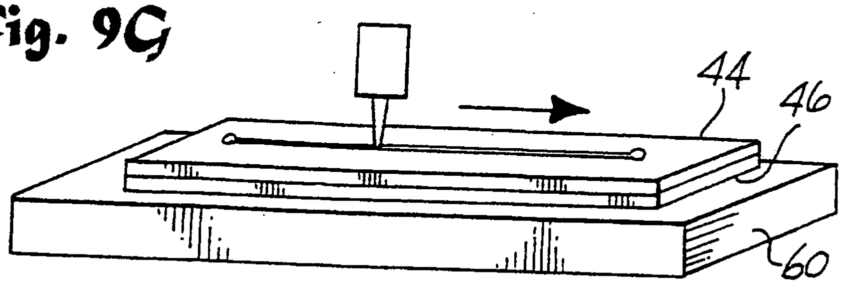


Fig. 10

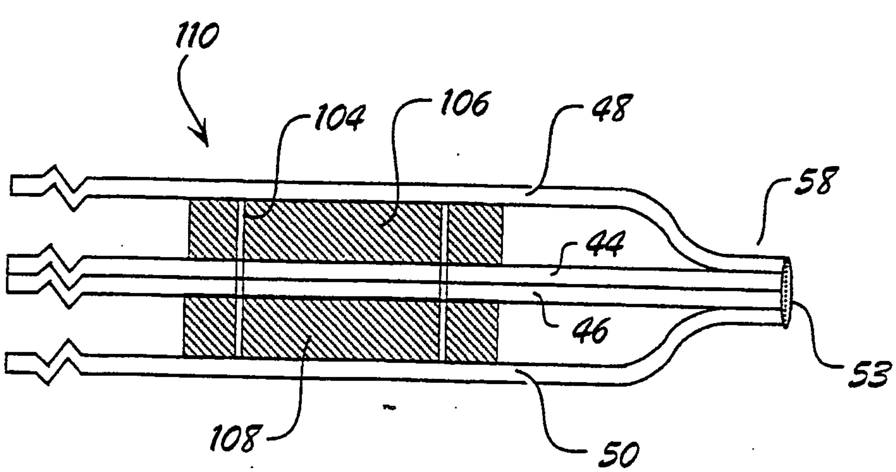


Fig. 11A

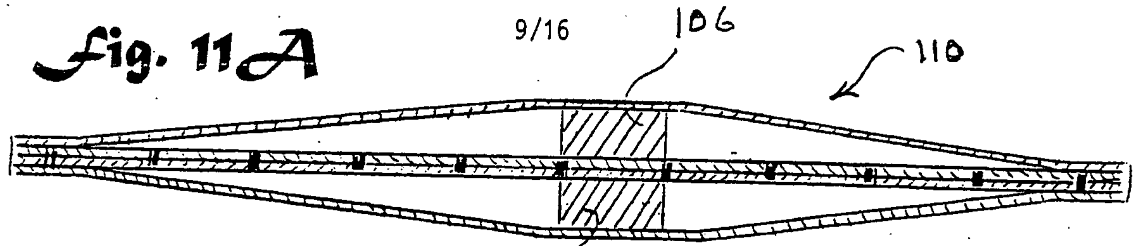


Fig. 11B

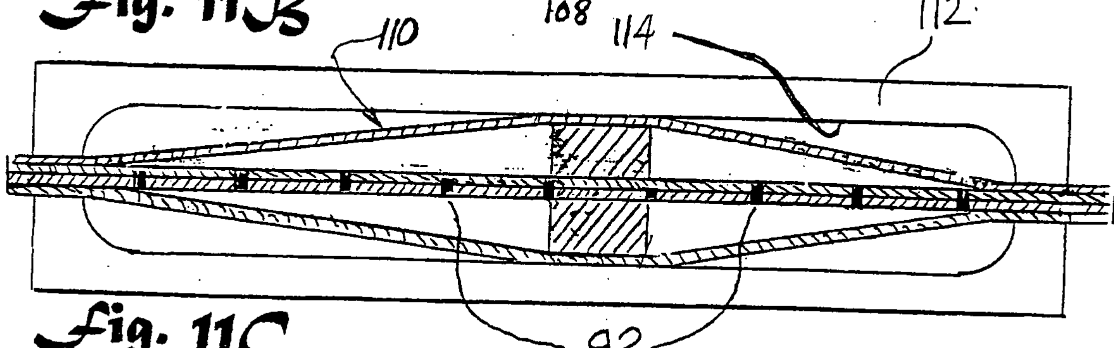


Fig. 11C

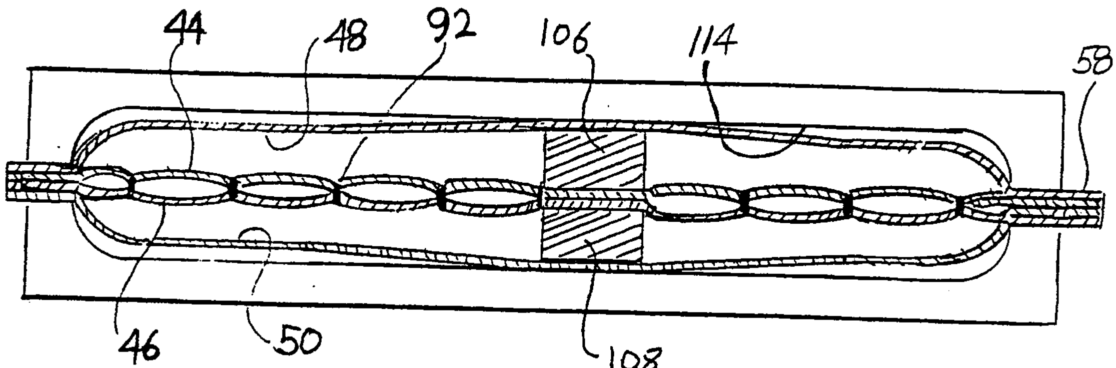


Fig. 11D

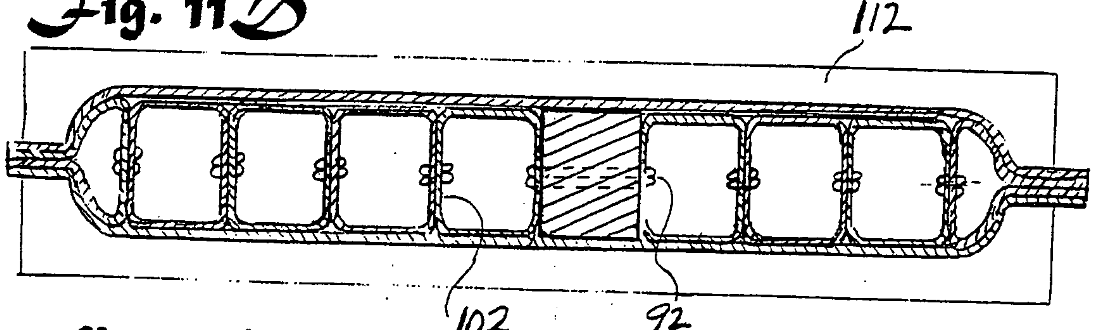
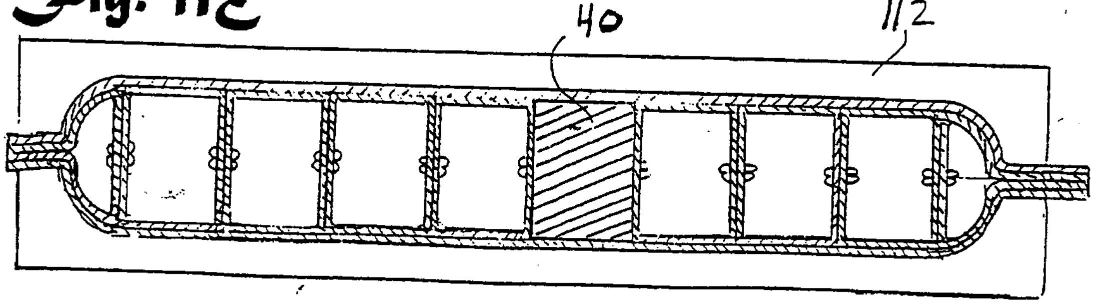


Fig. 11E



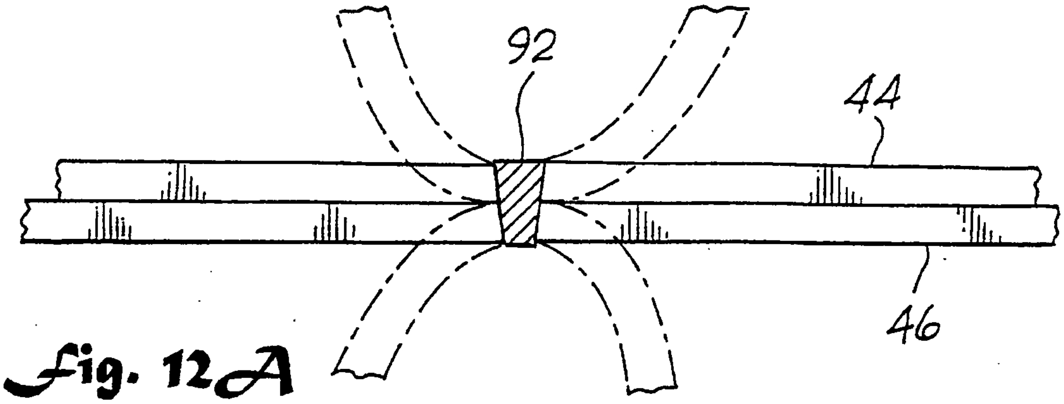


Fig. 12A

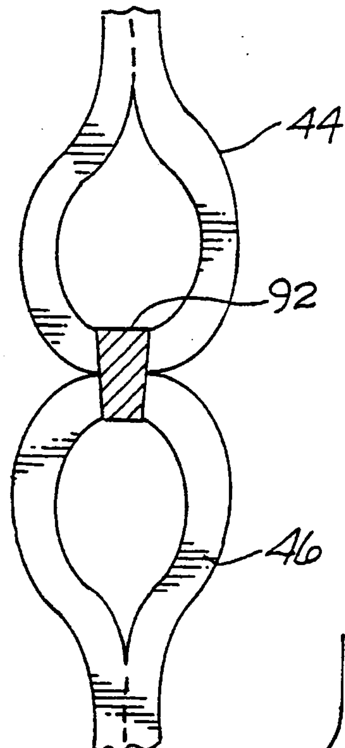


Fig. 12B

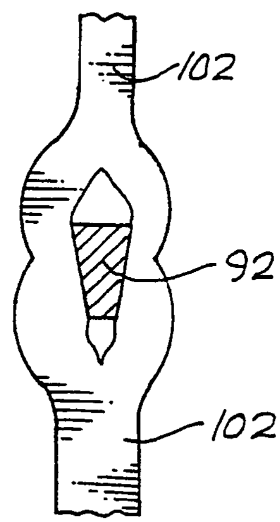


Fig. 12C

Fig. 13

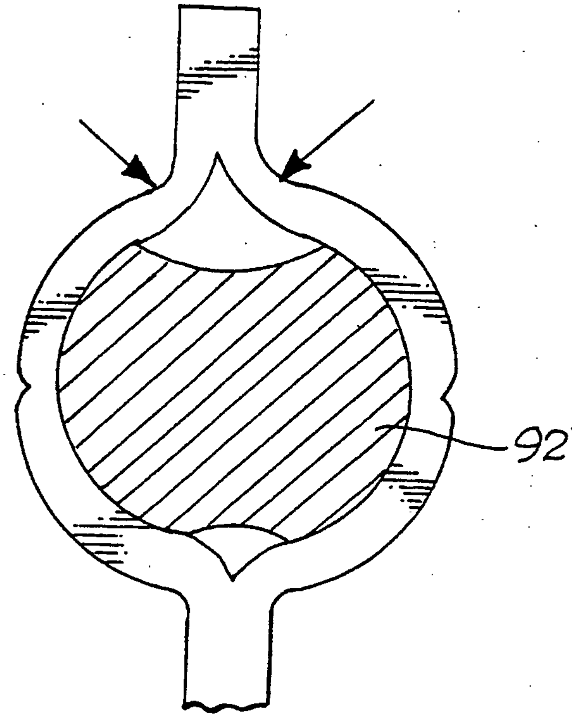
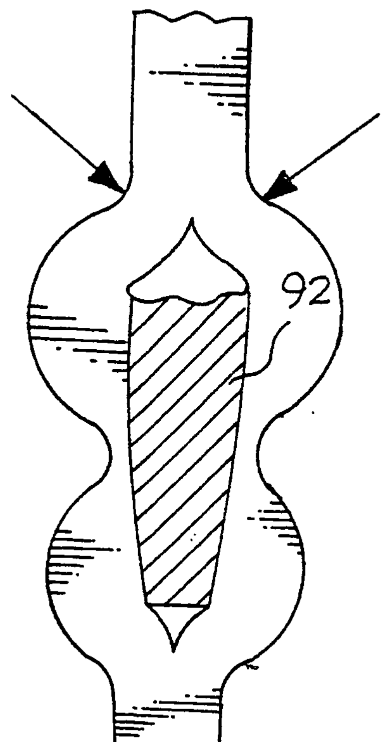


Fig. 14



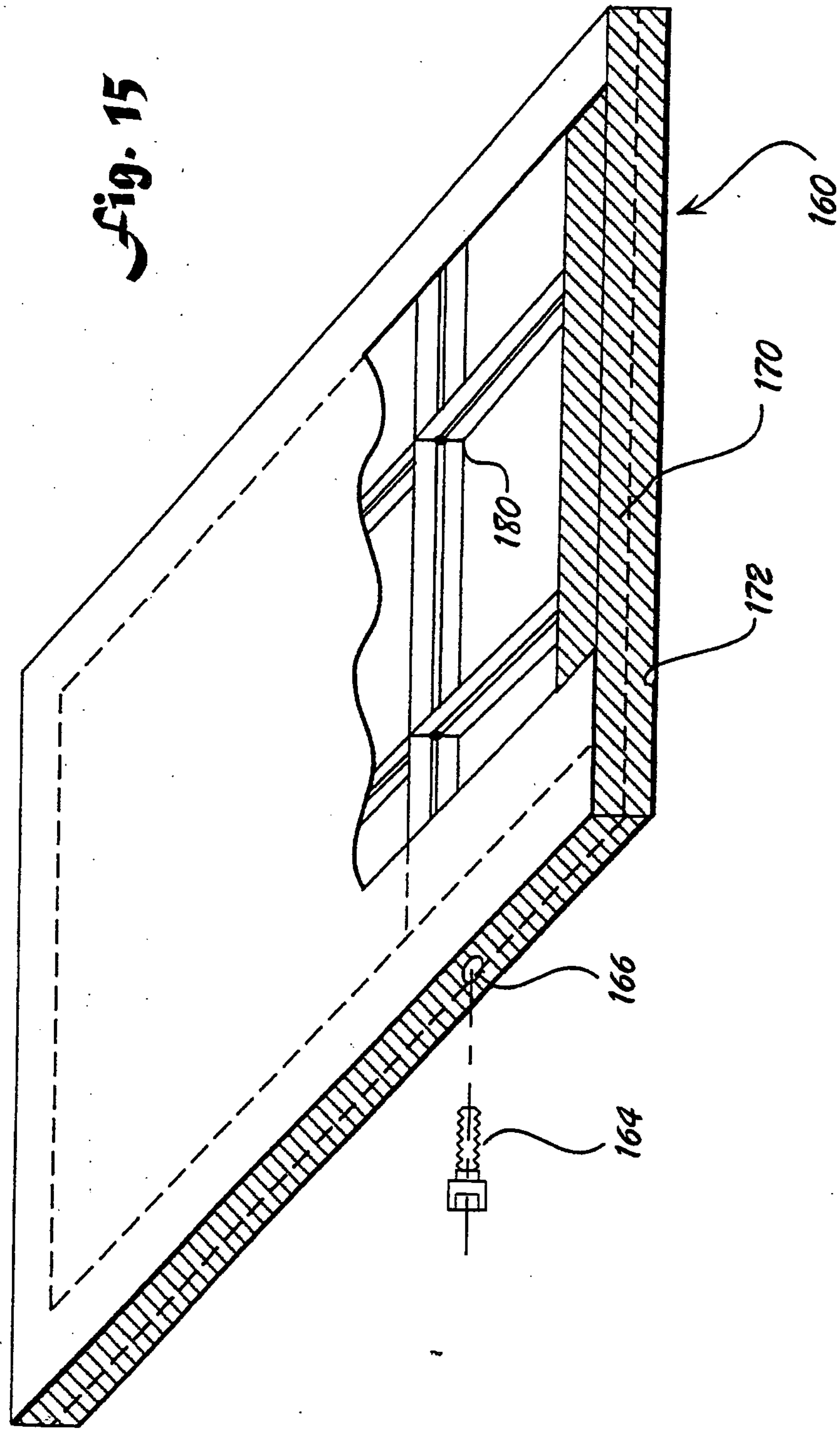


Fig. 15

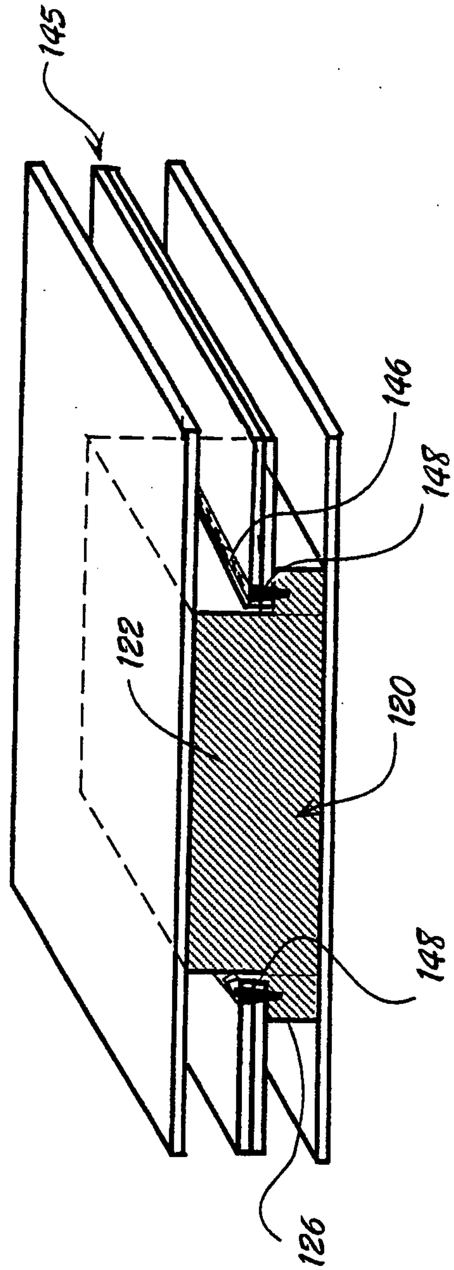


Fig. 16

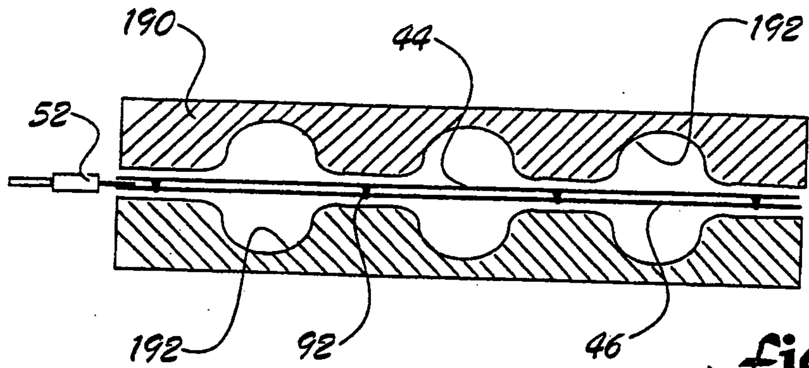


Fig. 17

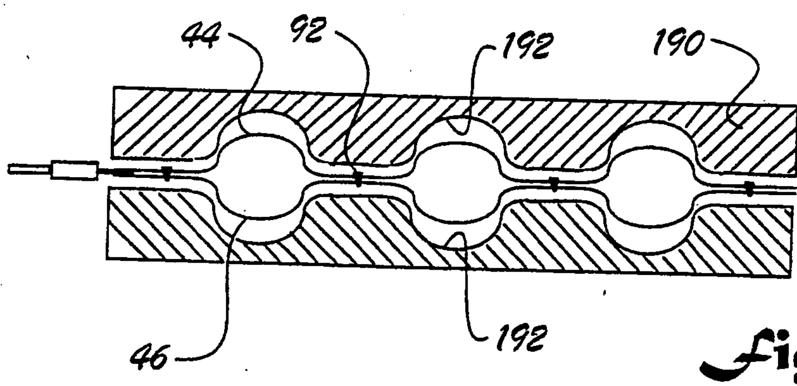


Fig. 18

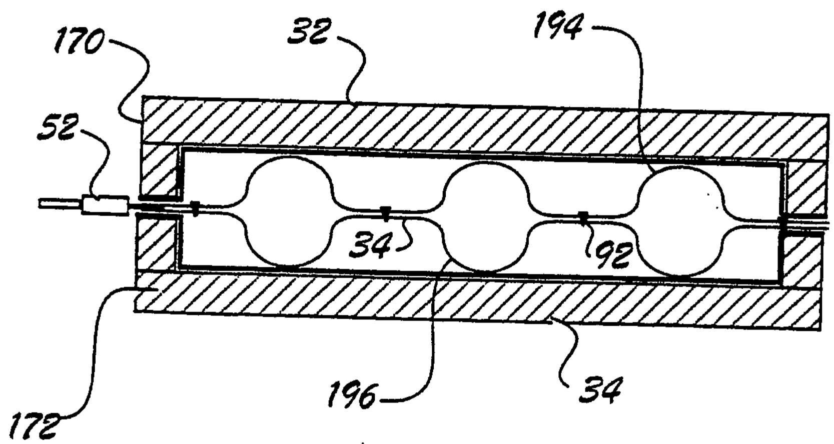


Fig. 19

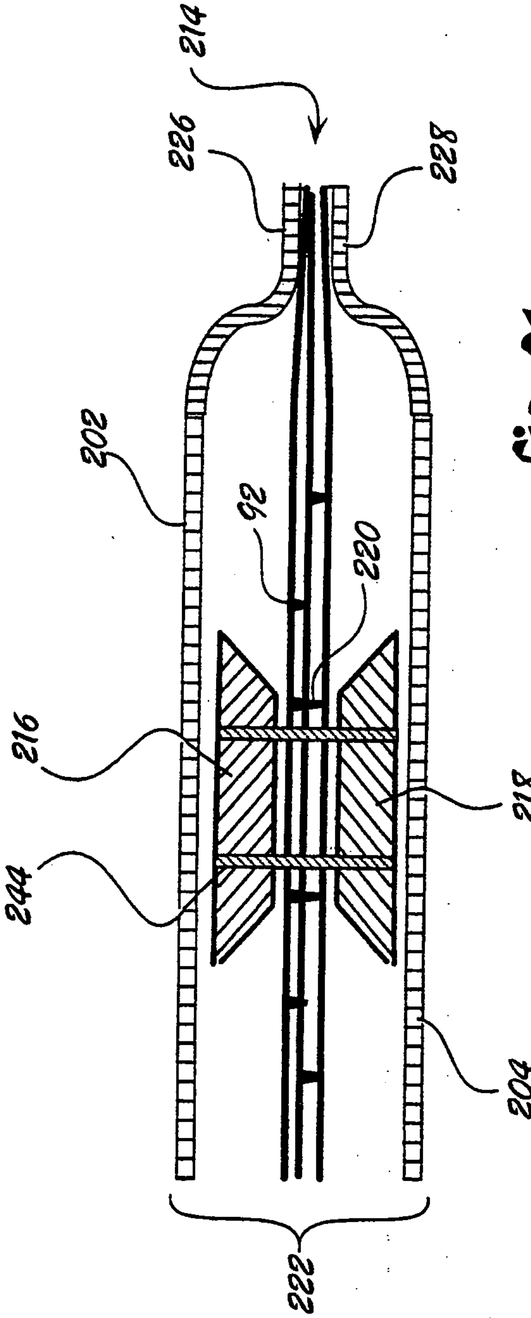


Fig. 21

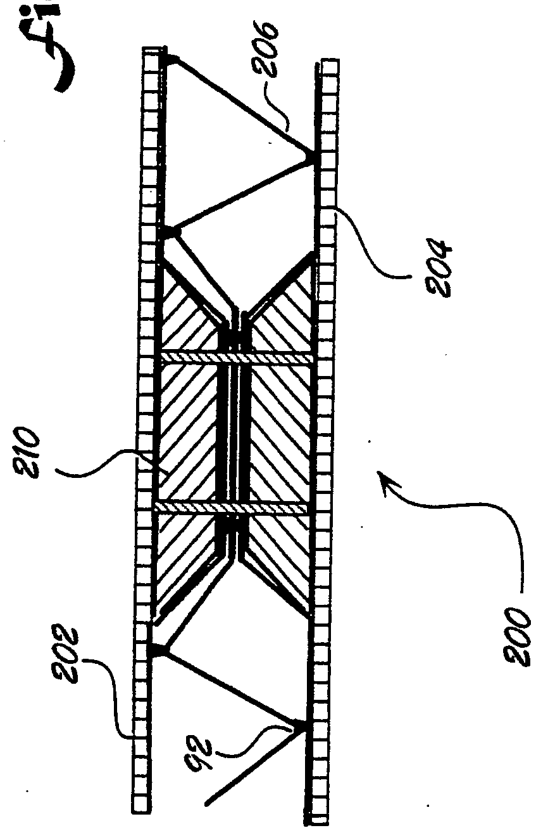


Fig. 20

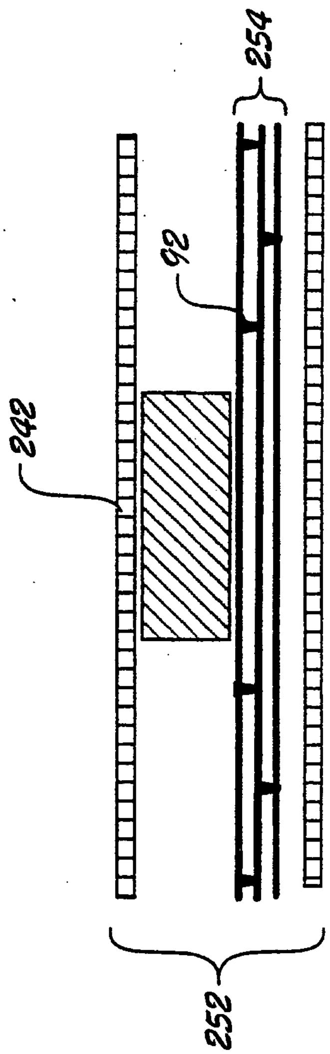


Fig. 23

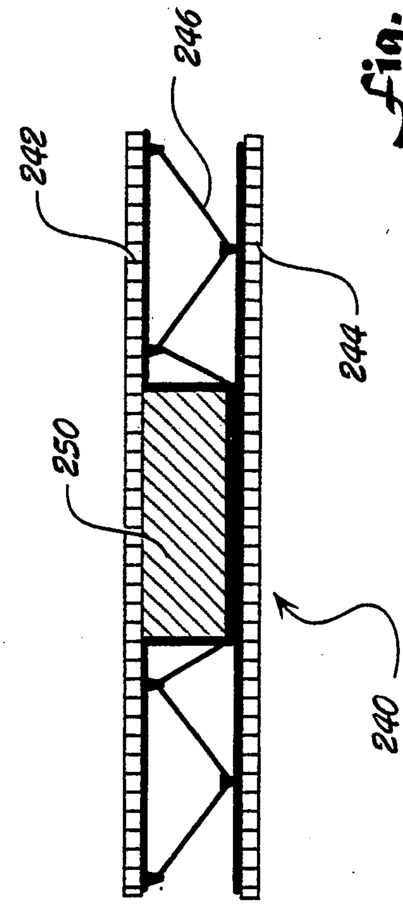


Fig. 22